Methods for Locating Legacy Wells

Onshore Unconventional Resources FWP

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R&IC/Field Monitoring Team

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Presentation Outline

- Project Overview- Well Locating Activities
  - Aeromagnetic surveys – challenges/results/findings
    - Private Marcellus Site (western PA)
    - Hillman State Park
    - Oil Creek State Park
    - Susquehannock State Forest
  - Fieldwork
    - Verification/validation of results
    - Evaluation of current inventories/databases
    - Site selection for other monitoring Team activities (fugitive methane measurements from unplugged, leaking wells)
  - Evaluation of miniaturized sensors deployed by UAS
    - MFAM

Benefit to the Program

- Unmapped, unplugged abandoned wells represent the greatest environmental risk from hydraulic fracturing

- Rapid and cost-effective methods to locate abandoned wells will allow operators to mitigate environmental risk

Project Overview: Goals and Objectives

- Develop rapid and cost-effective methods for locating legacy wells.
  - Use public information that is widely available at low or no cost.
  - Use airborne methods that are rapid, can be applied to areas with terrain and vegetation challenges, and avoid landowner issues
  - Provide a complete catalog of existing well locations at test sites

Technical Status

- Project has met all initial goals;
- New, tougher goals have been established
  - Methods are currently being optimized to be effective for the most challenging wells
  - Well location survey costs are being reduced by the incorporation of UAV

Methods for Locating Legacy Wells

Garret Veloski, Richard Hammack, James Sams

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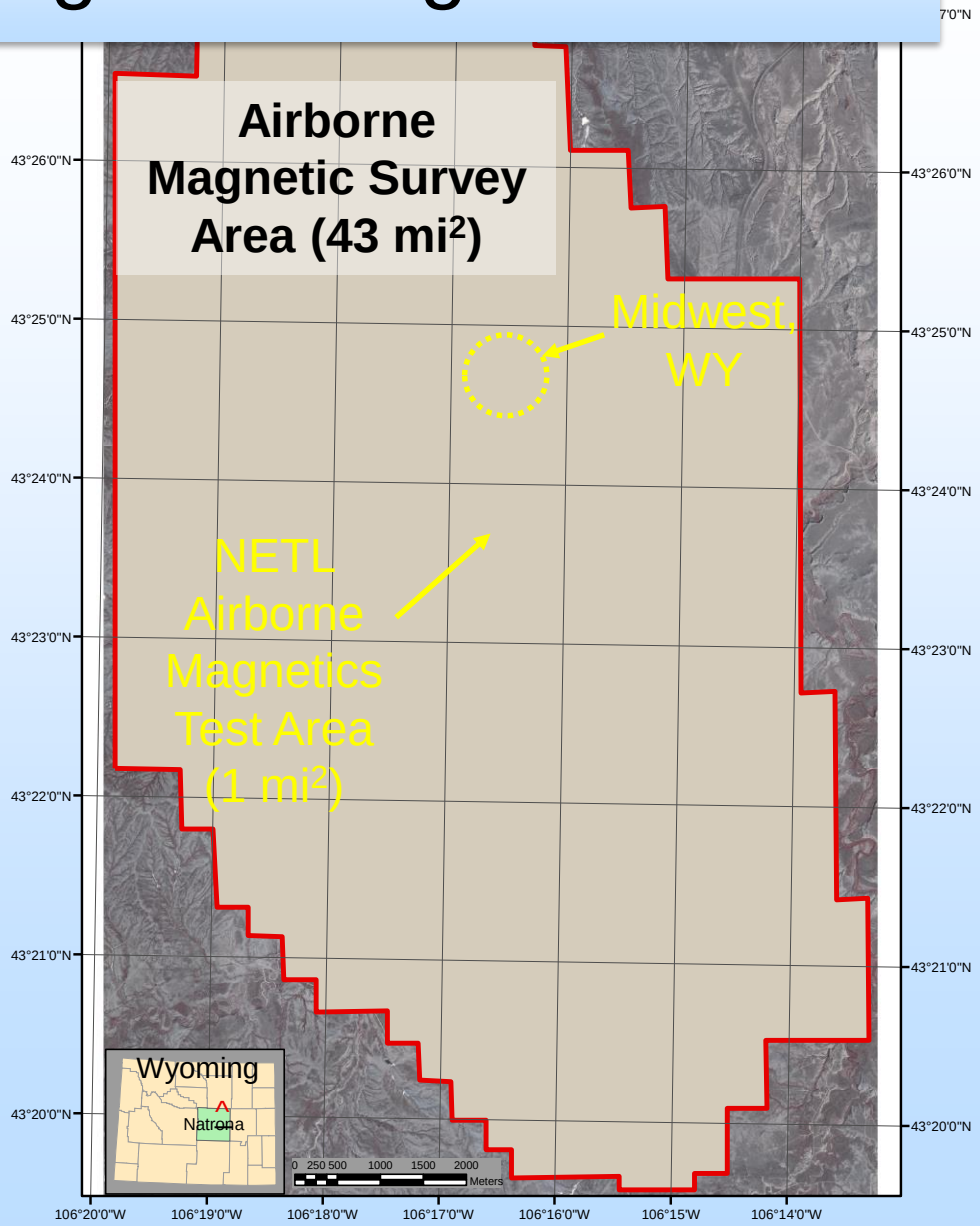
Locating Wells Using Aeromagnetic Data

Salt Creek Oil Field Midwest, Wyoming 2005

– Operator planned CO_2 flood (EOR)

Approach

- Helicopter survey using two boom-mounted magnetometers
- Detects the unmistakable “bull's-eye” magnetic signature of vertical steel well casing

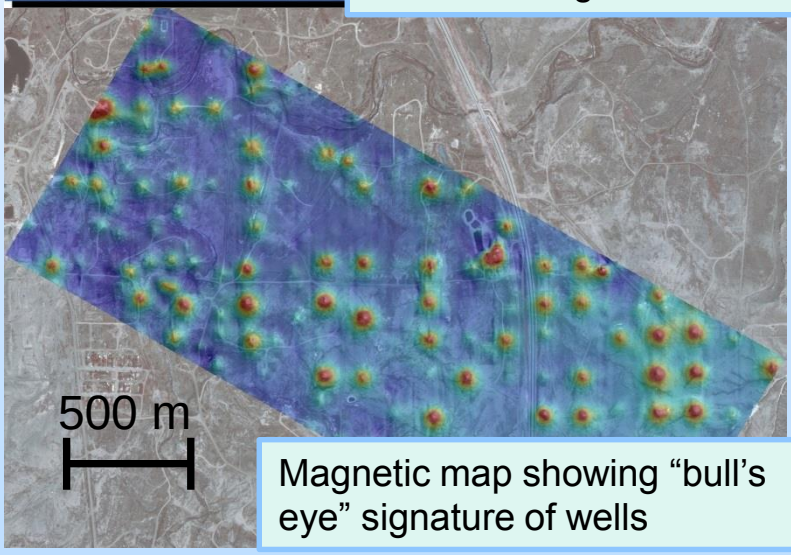


Locating Wells Using Aeromagnetic Data

Results from Test Area

- Method located 100% of wells drilled for primary production (1912-1926)
- Method located 82% of wells drilled for secondary recovery (water flood, 1965-1990)
- Based on success locating old wells at test area, operator used helicopter method to survey entire oilfield (43 mi^2)

Helicopter with two boom-mounted magnetometers

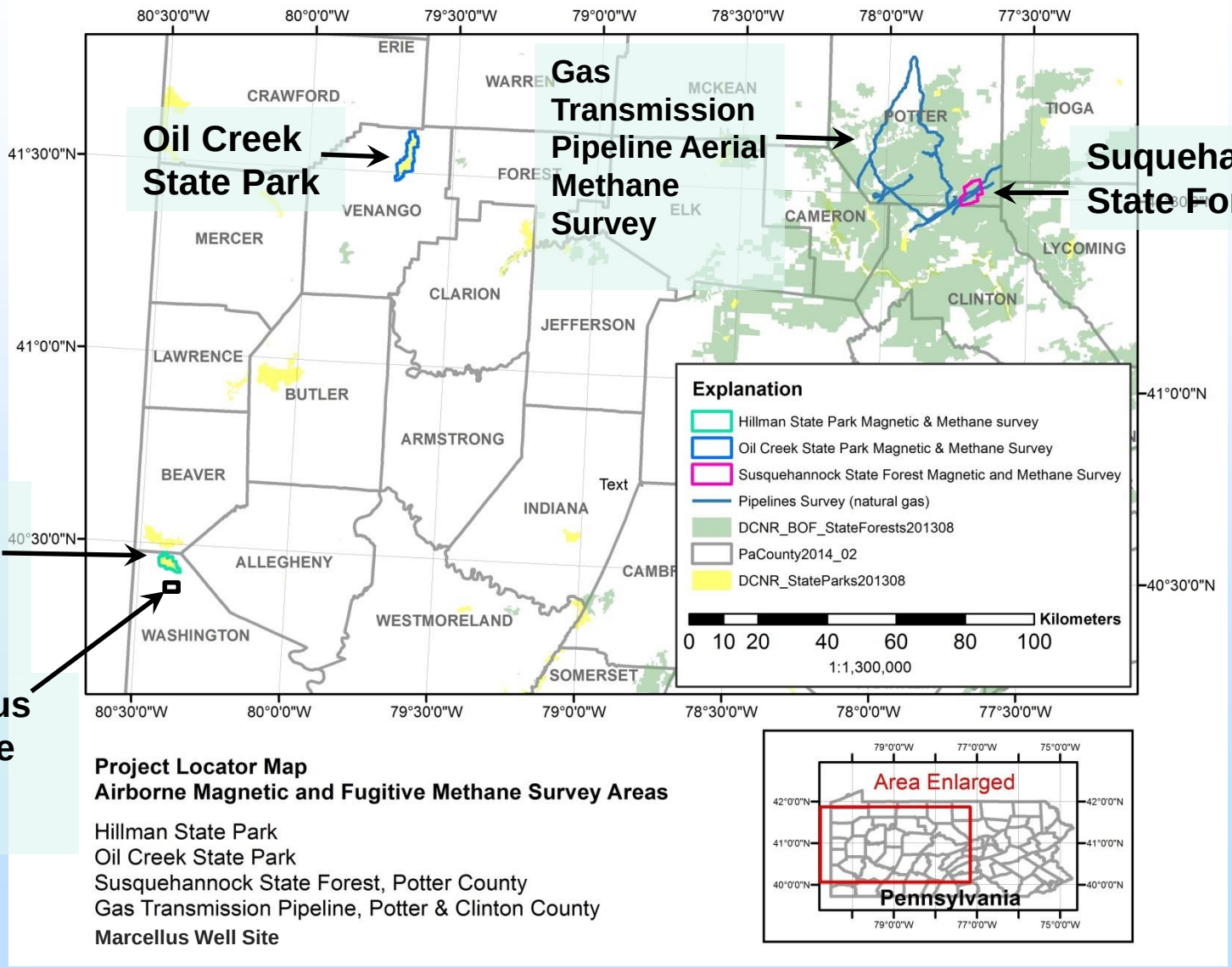


Magnetic map showing “bull’s eye” signature of wells

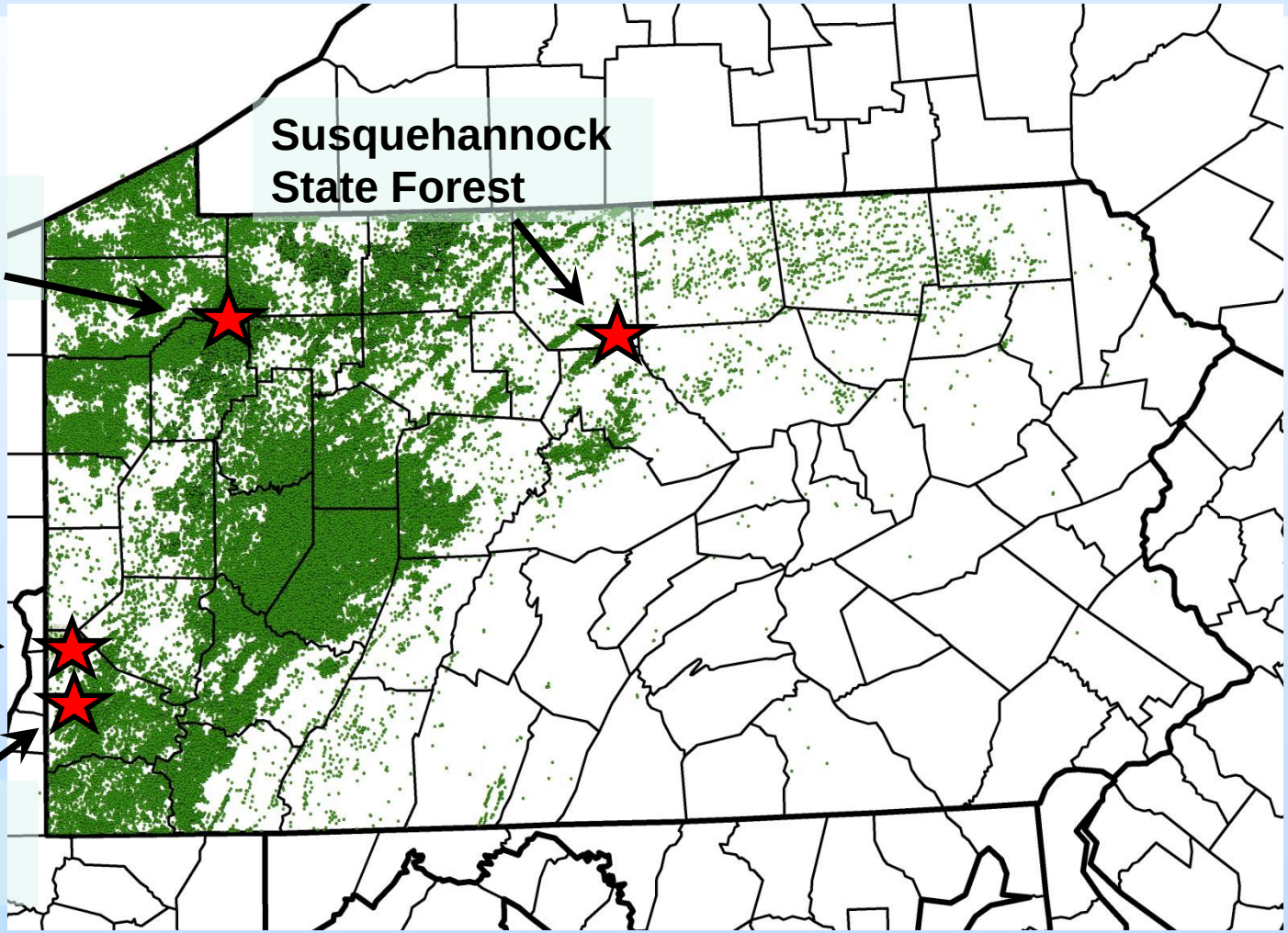
Legacy Wells in Pennsylvania

- >150,000 wells recorded in PA Internet Record Imaging System Wells Information System (PAIRIS/WIS) + paper records > 330,000(?) wells
- Many unrecorded, orphaned or otherwise abandoned and/or unmarked, unplugged or improperly plugged
- Location data suspected to be inaccurate
- No casing required prior to 1921
- No registration required prior to 1955
- No drilling permits or bonds for abandonment, no specific plugging requirements prior to 1984

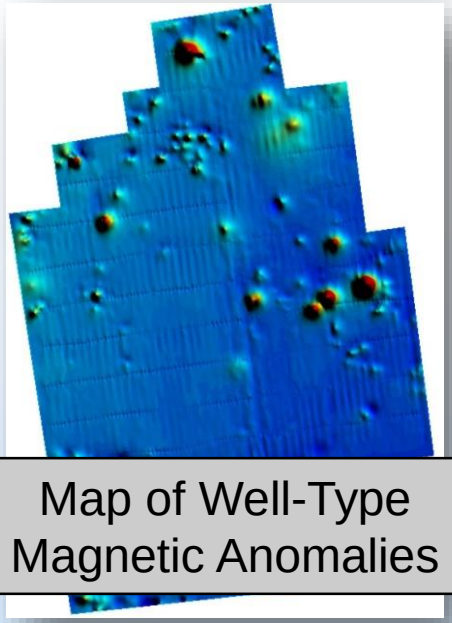
Helicopter Magnetic and Methane Surveys of PA State Lands with Legacy Oil and Gas Wells



Pennsylvania Internet Record Imaging System Wells Information System (PAIRIS/WIS) Well Locations



Marcellus Site



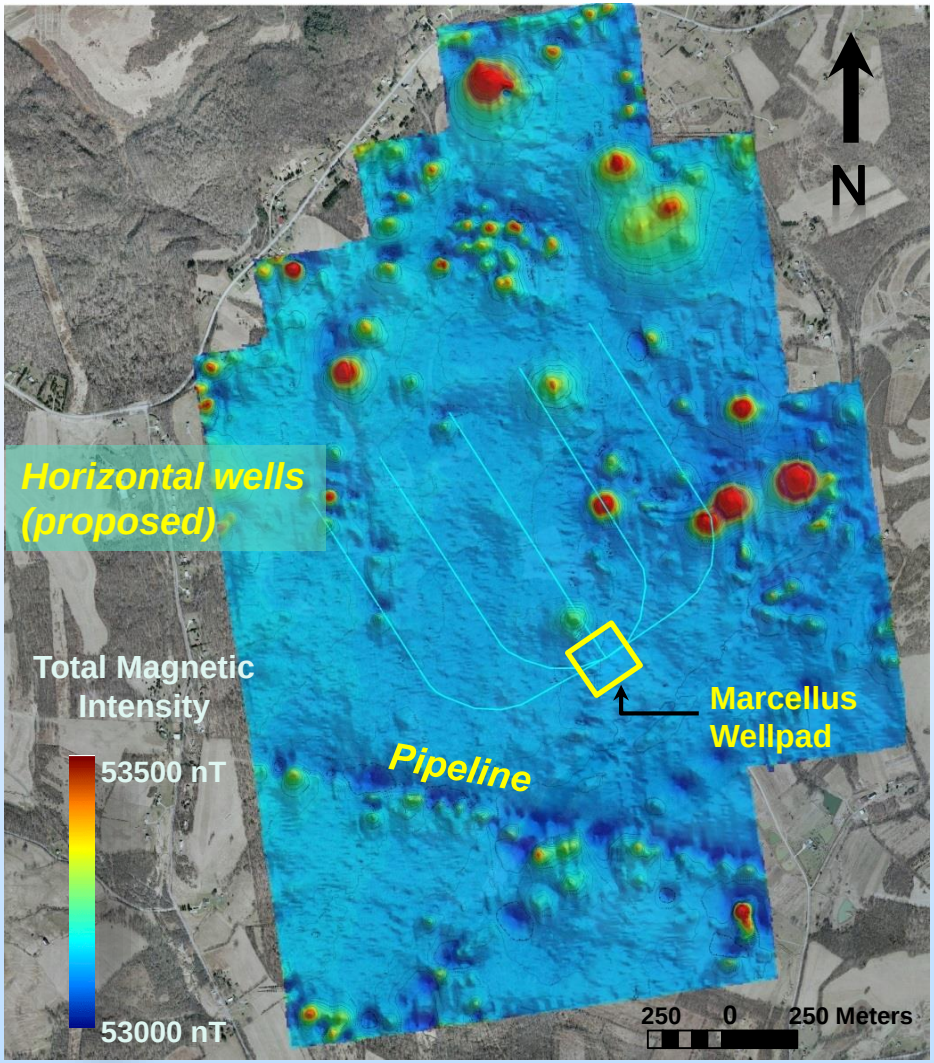
Map of Well-Type Magnetic Anomalies

Navigating to Magnetic Anomaly Location

Locating Magnetic Anomaly on the Ground

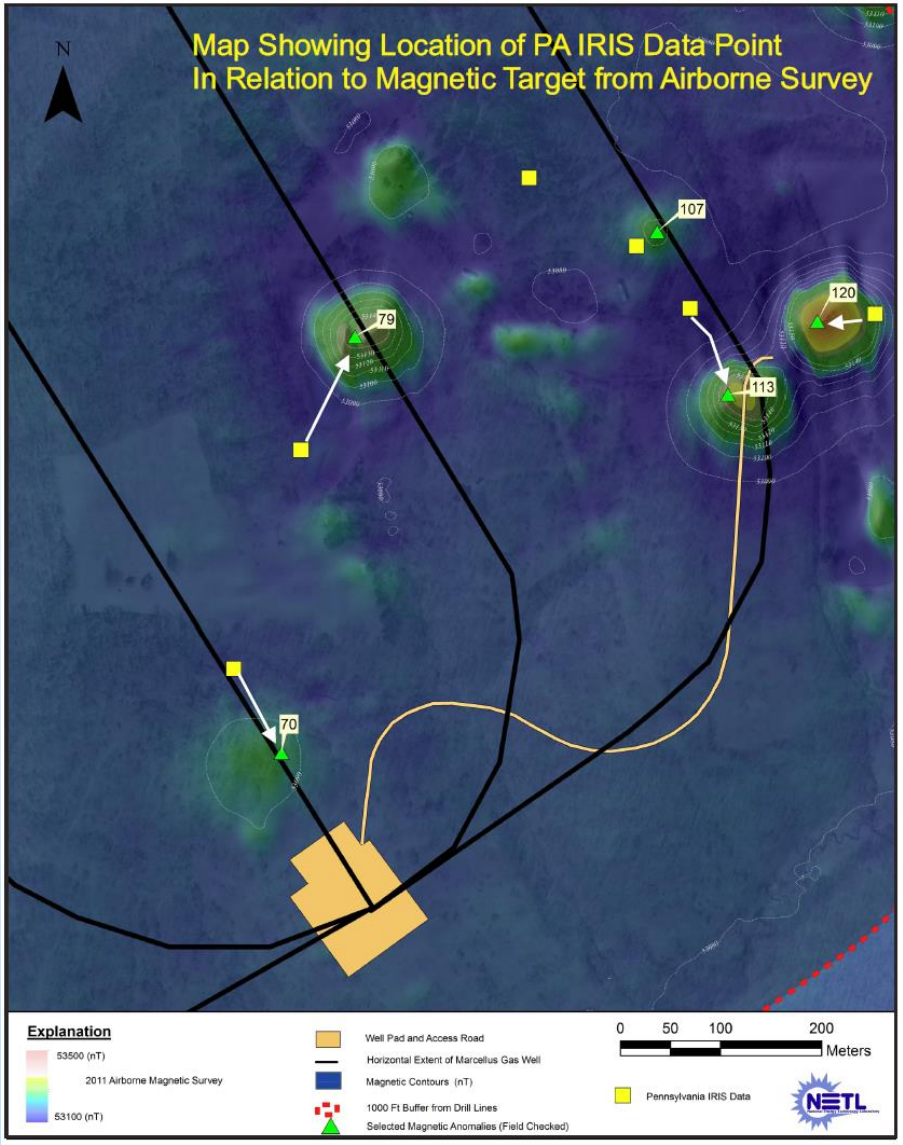
Excavation to Confirm Well Location

Marcellus Site



Helicopter Magnetic Map of Proposed Marcellus Well Pad Location

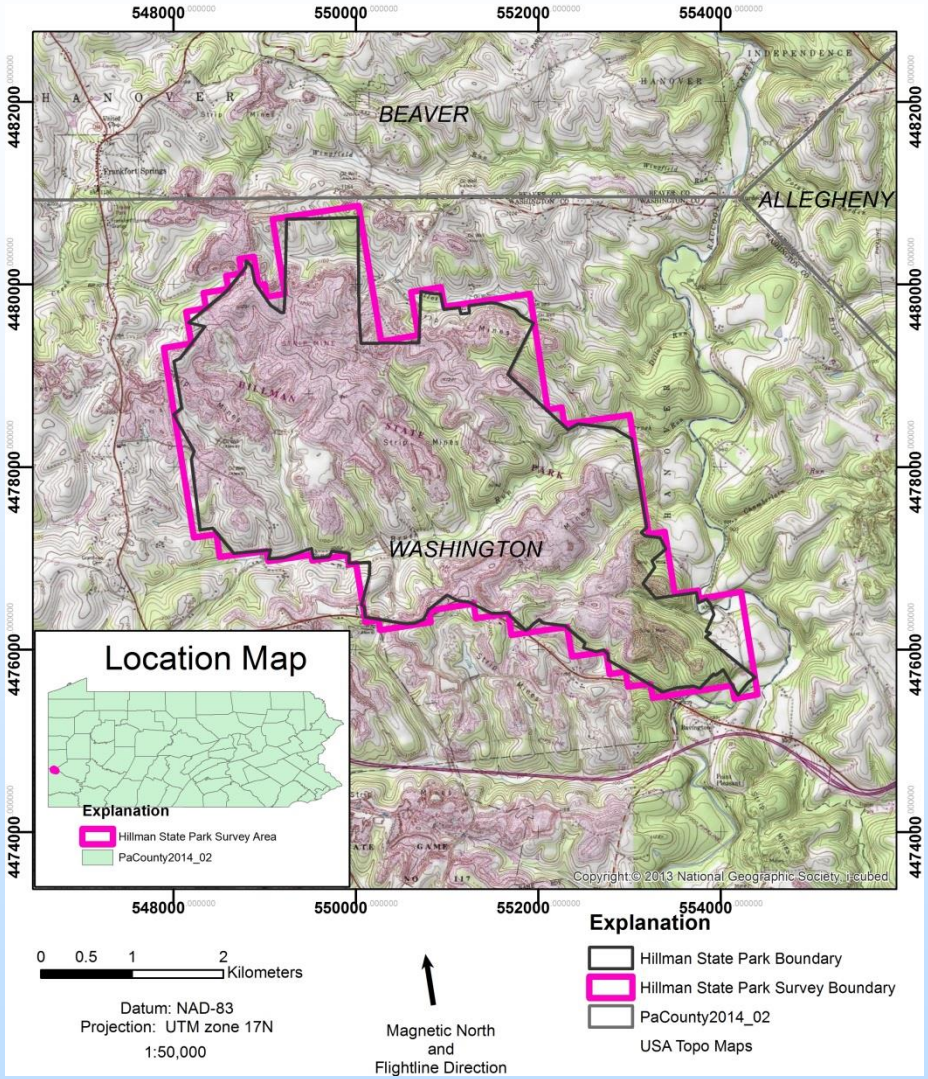
Marcellus Site



How Accurate are Well Databases?

- PA IRIS database well positions often > 100 m from actual well locations
- 17 wells located in study area; six were in PA IRIS well database
- Some locations in PA IRIS not close to any confirmed well

Hillman State Park

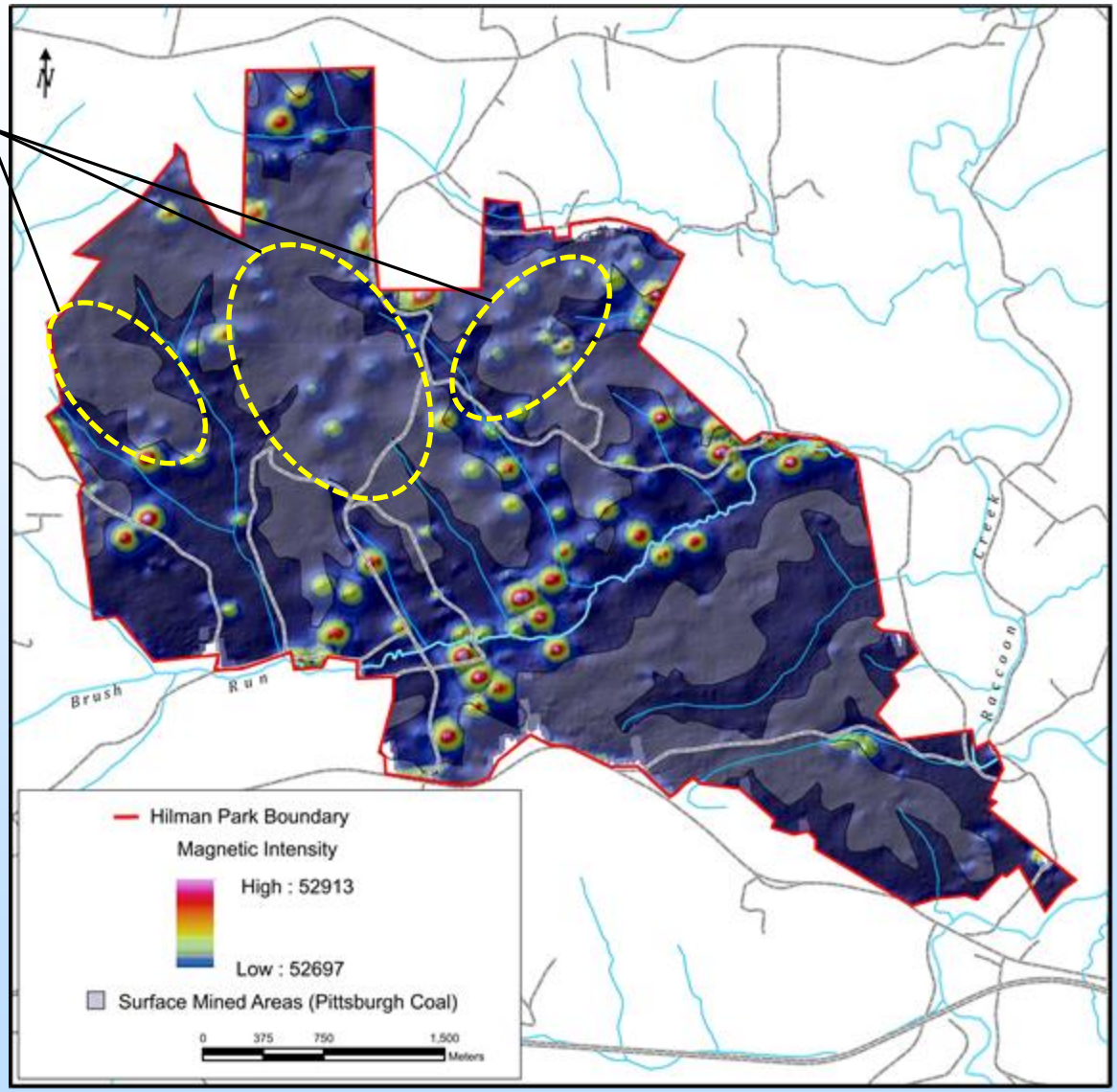


Survey Statistics

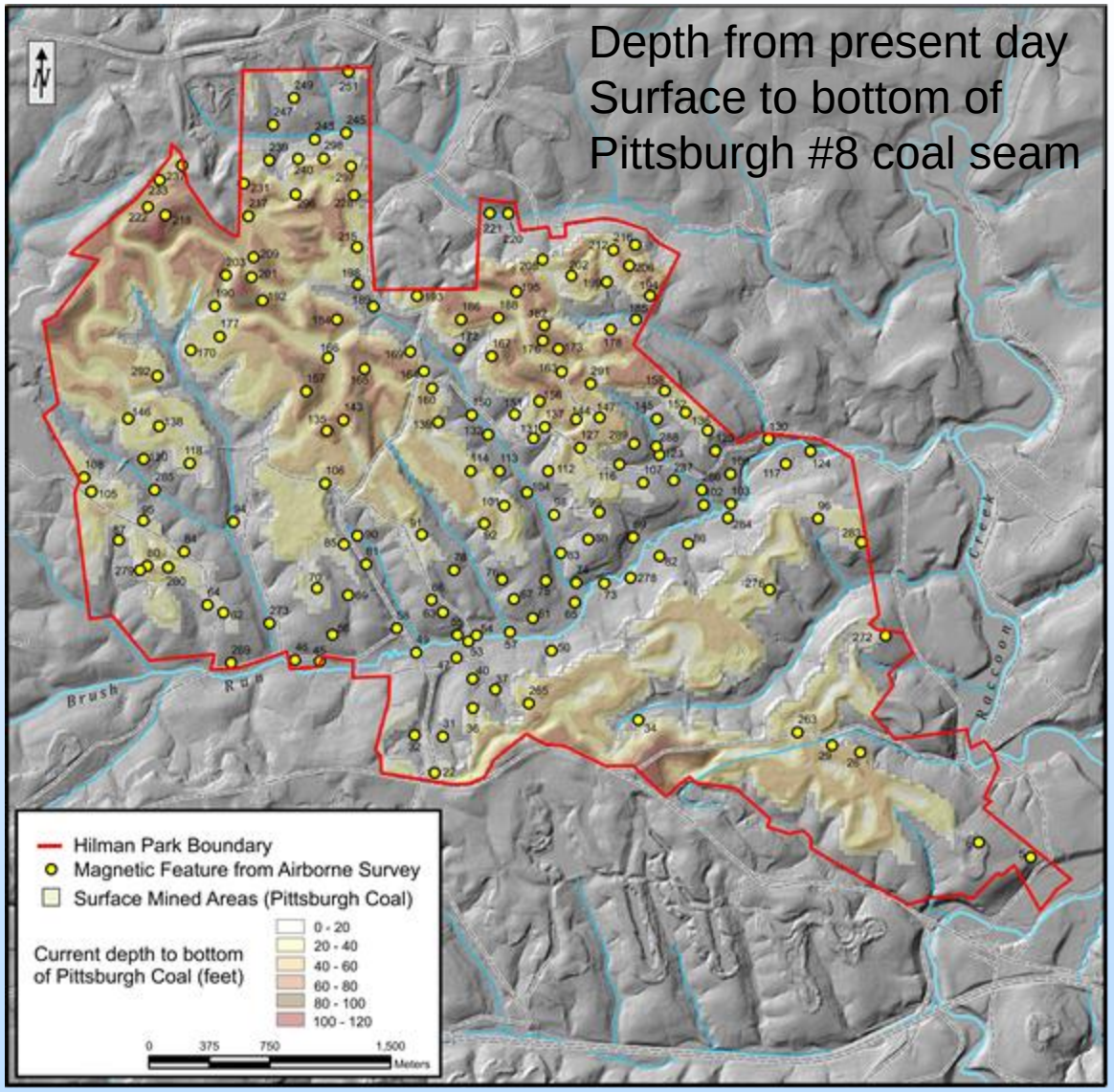
- **17.7 km²**
- **416419 samples (both sensors)**
- **622.1 line-km**
- **Altitude 46.1 m AGL**
  - (range: 22.3-166.2 m, sigma: 10.5 m)

Hillman State Park

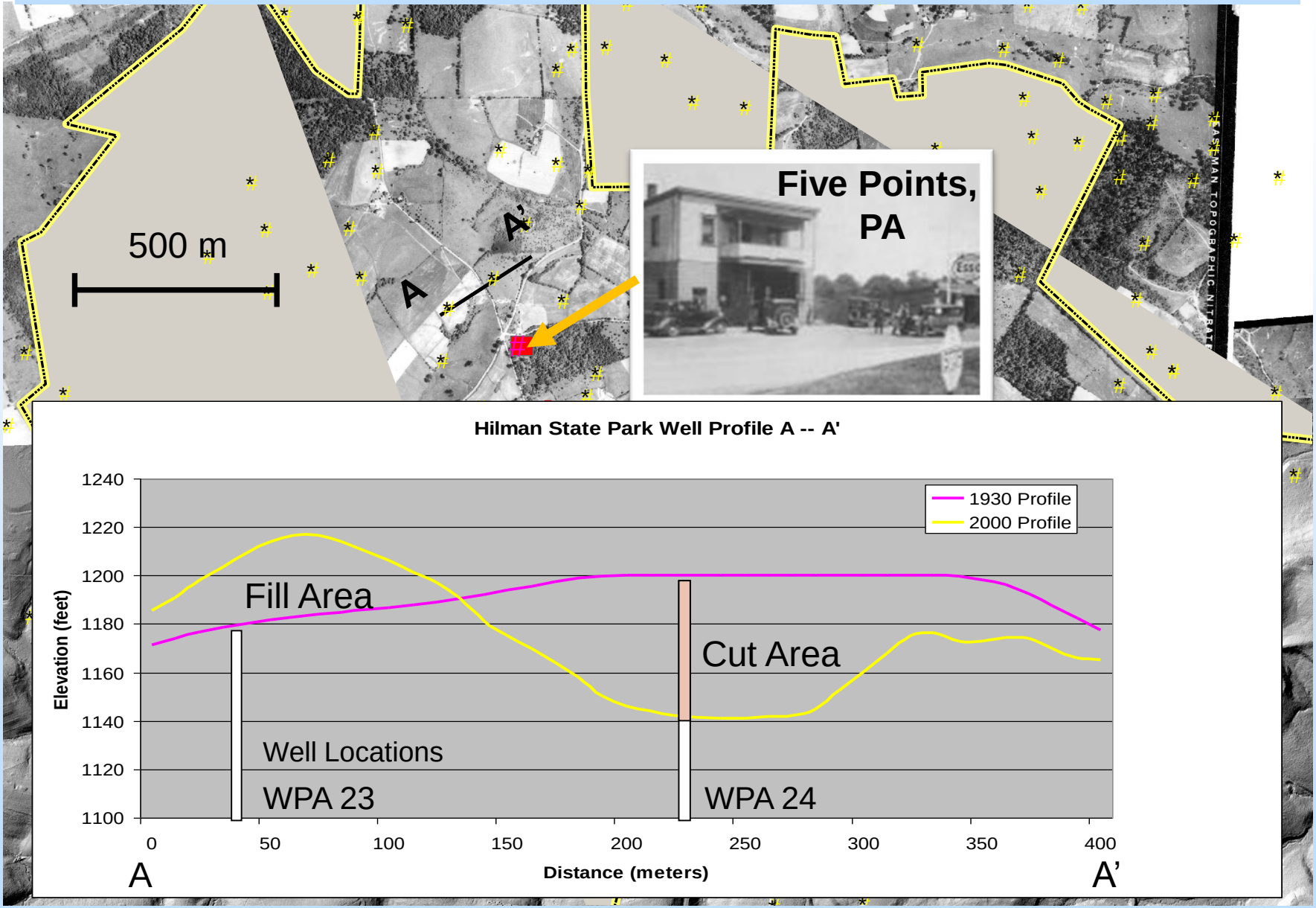
Subdued intensities of Well-type Magnetic anomalies within the surface-mined areas



Hillman State Park

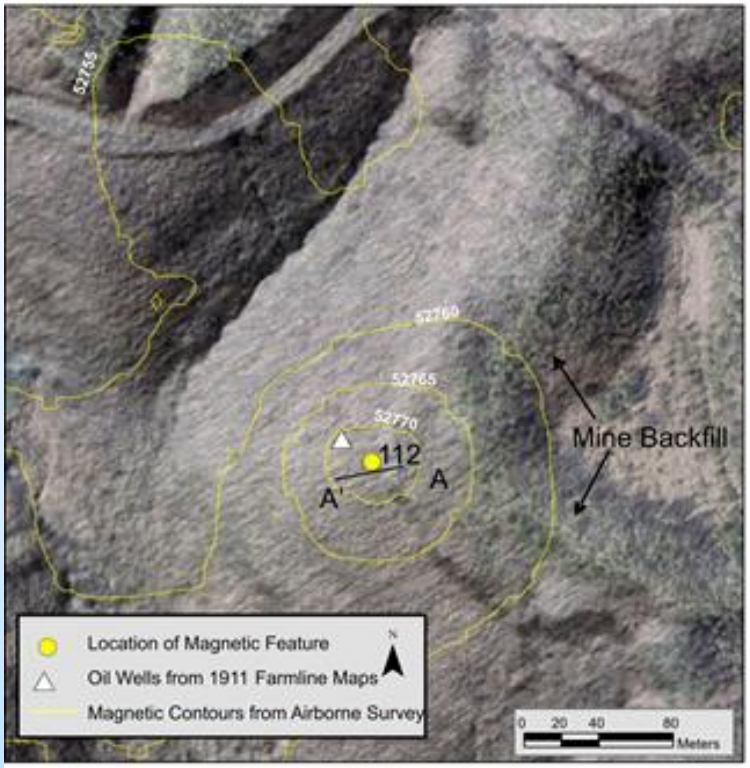


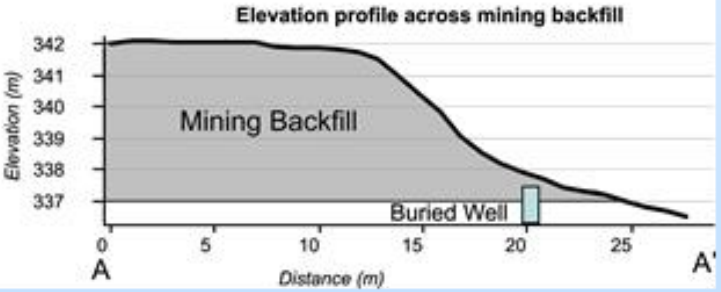
Hillman State Park



Hillman State Park

Site 112





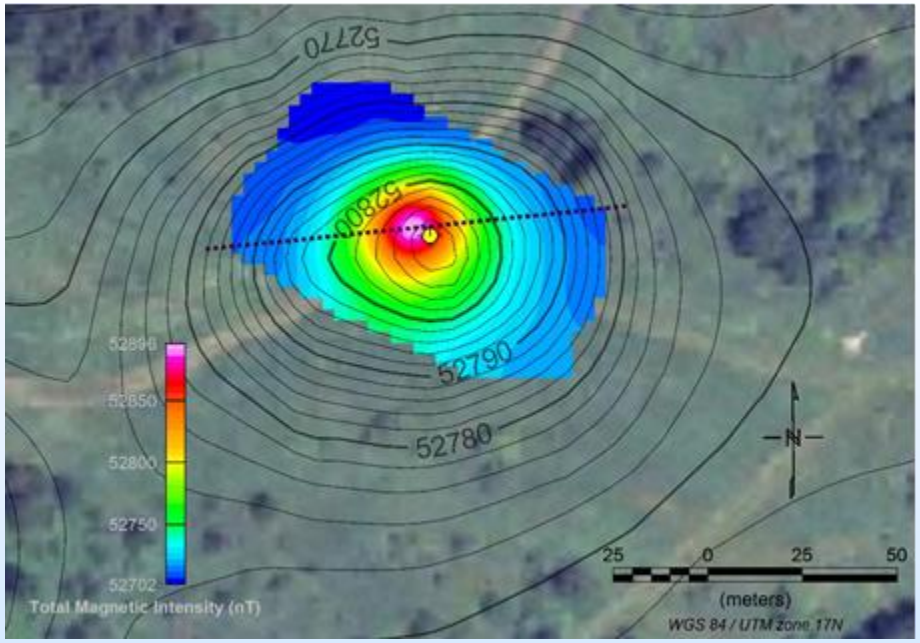
Buried wells in surface-mined areas

Hillman State Park

Site 112. Open wellbore

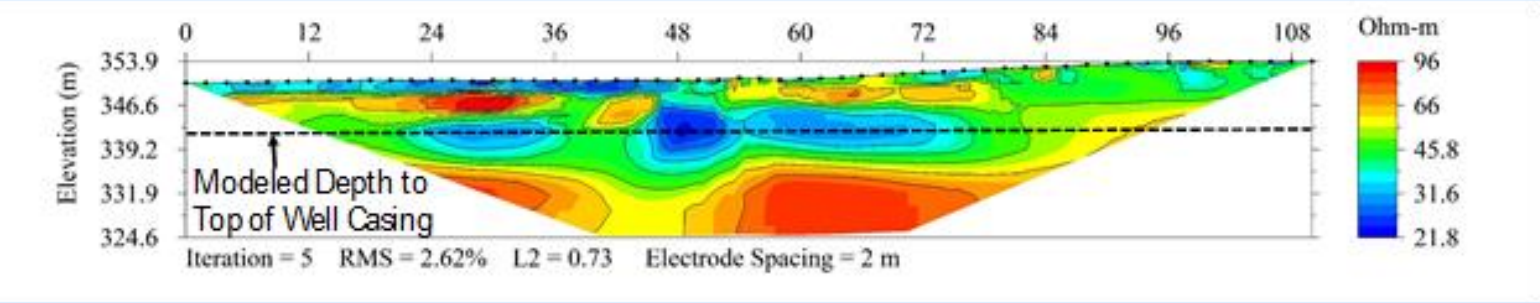
Oilfield artifacts

Hillman State Park



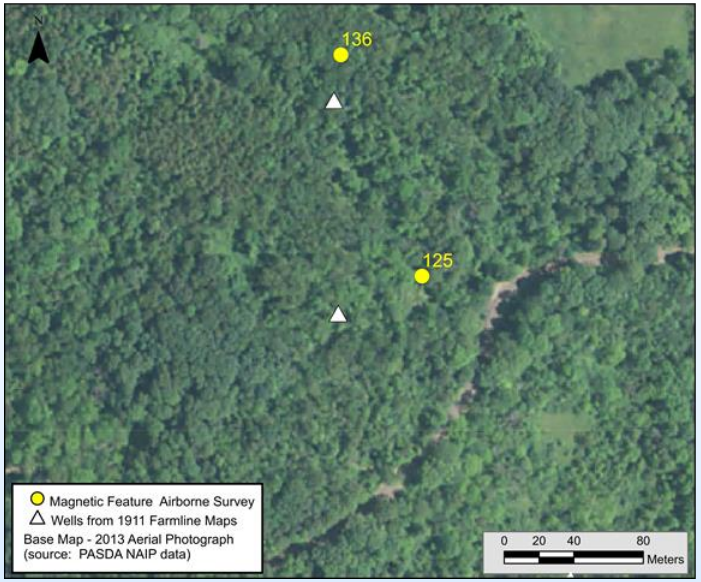
Ground magnetic survey and resistivity Array location over a buried well

Resistivity Survey in remediated surface-mined area

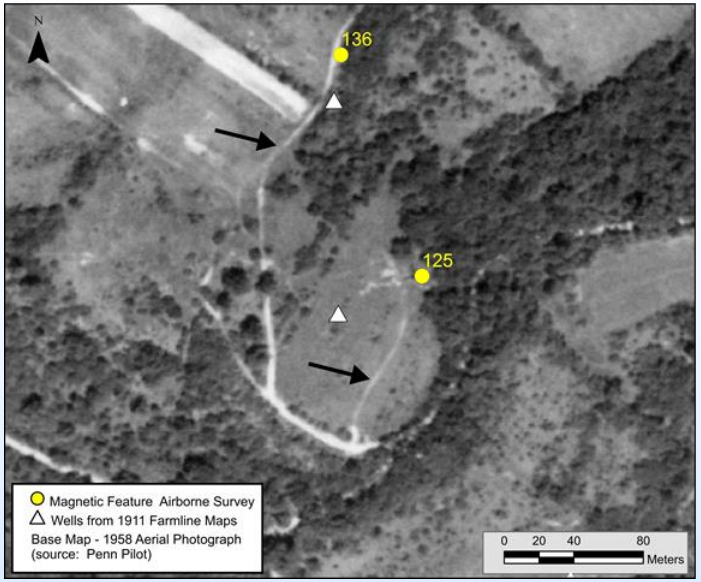


2D resistivity inversion model for estimating depth to buried well casing

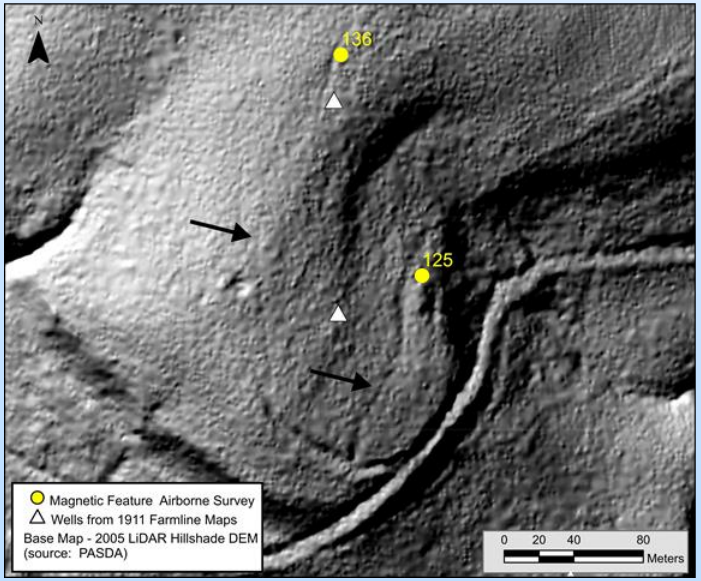
Hillman State Park



2012 Air Photo

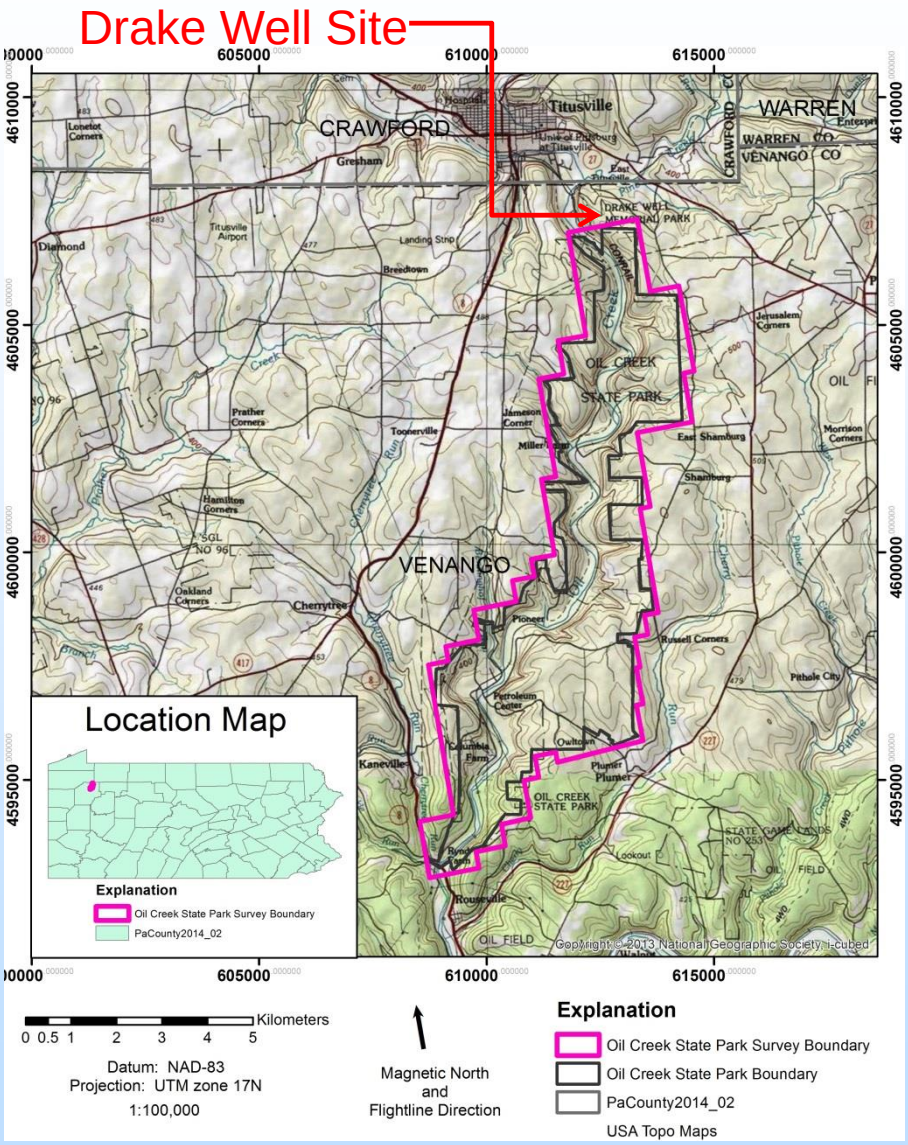


1958 Air Photo



2005 LiDAR DEM

Oil Creek State Park



Survey Statistics

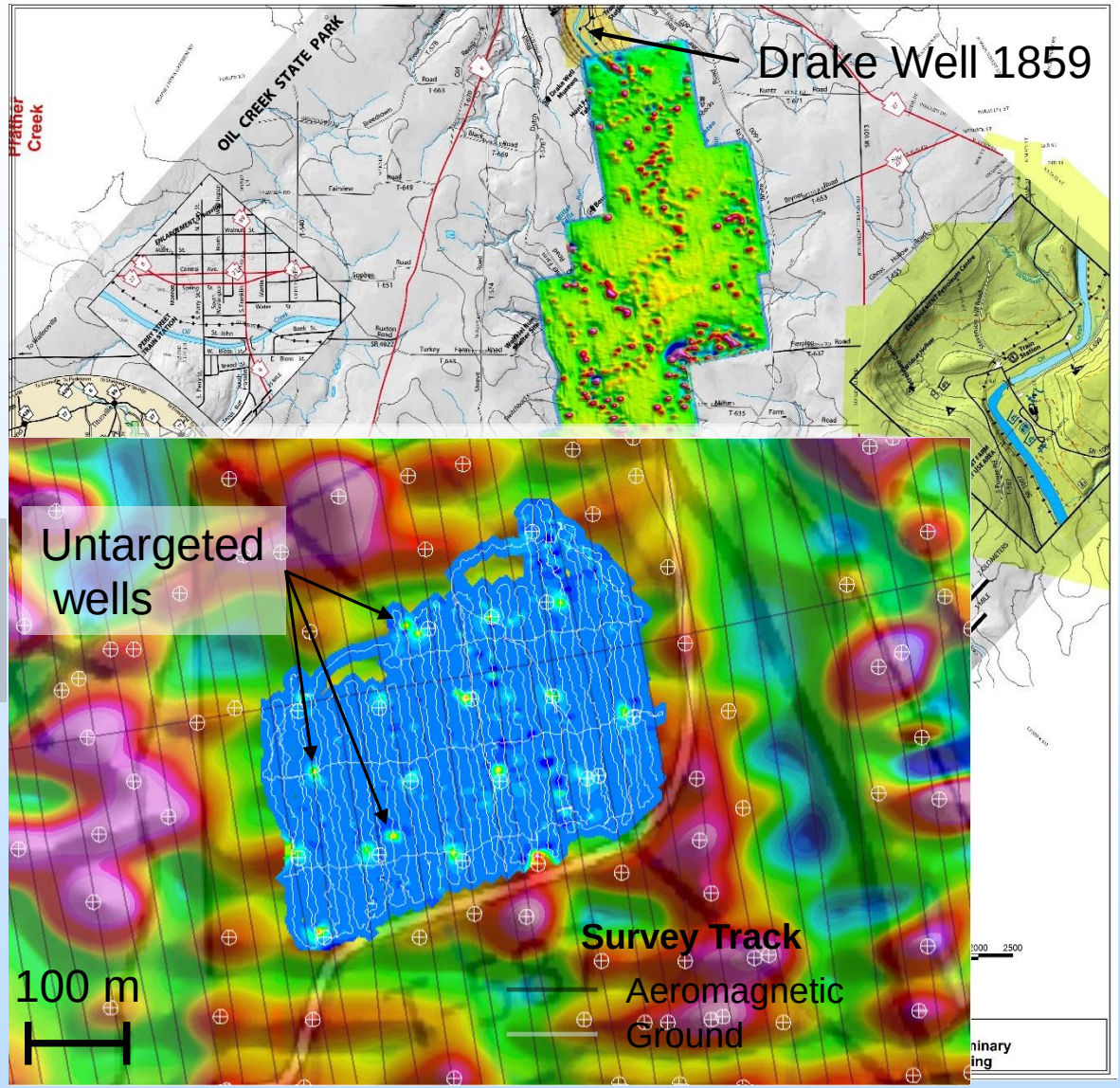
- 37.7 km^2
- 786505 samples (both sensors)
- 1244.6 line-km
- 51.0 m AGL
  - **(range: 17-174 m, sigma: 9.2 m)**

Oil Creek State Park

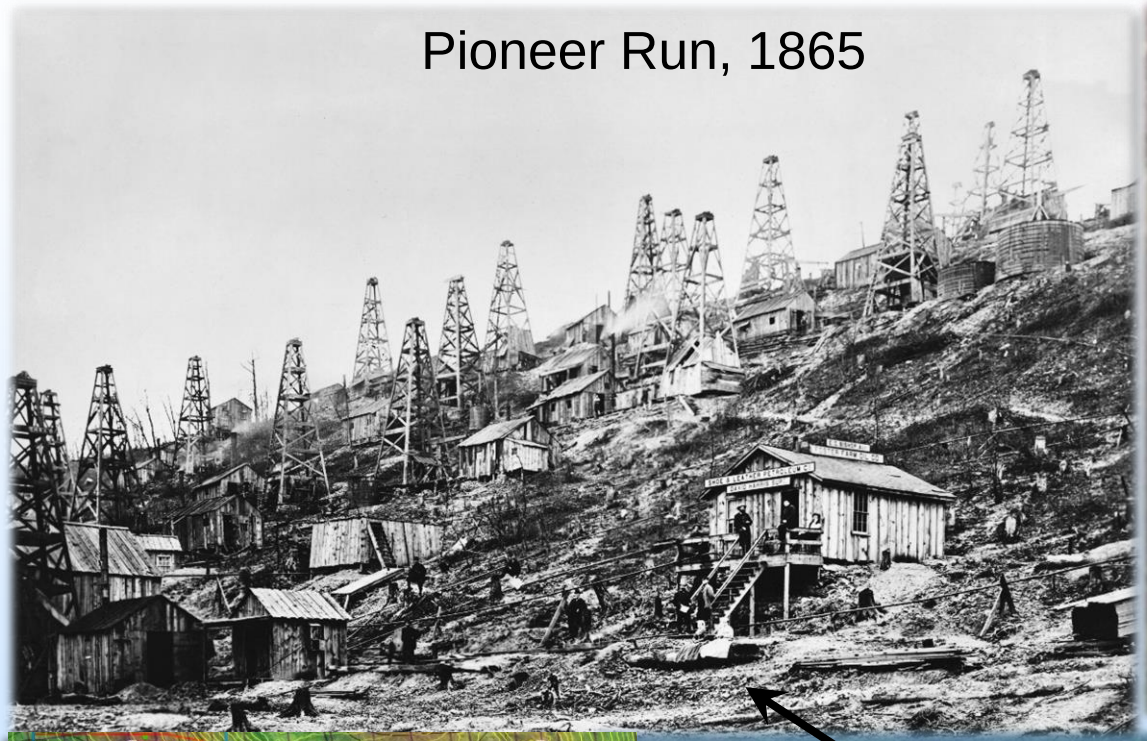
Total Magnetic Intensity

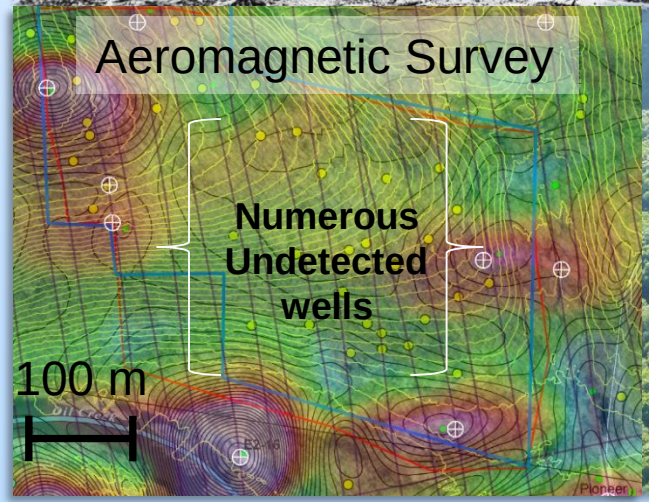
Analytic Signal

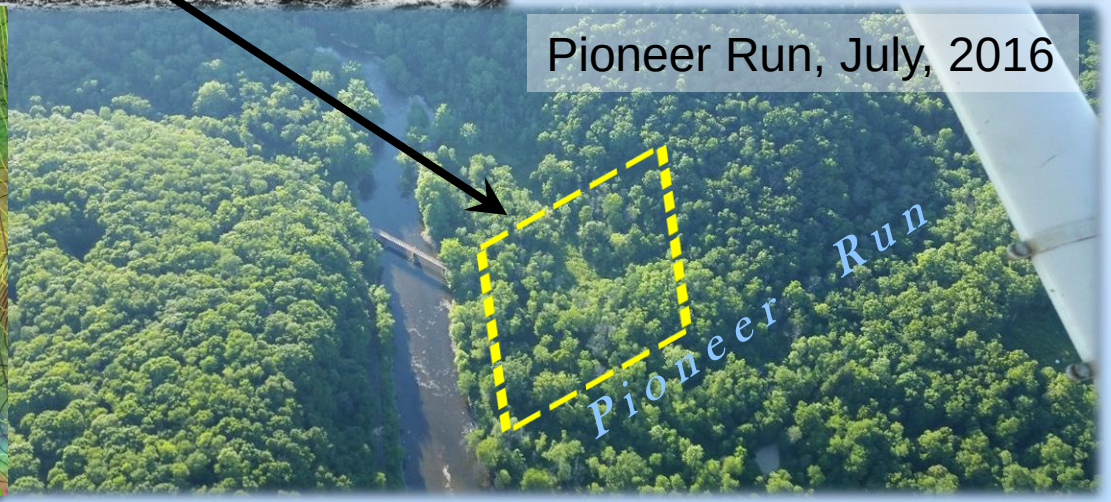
Calculated Vertical Gradient



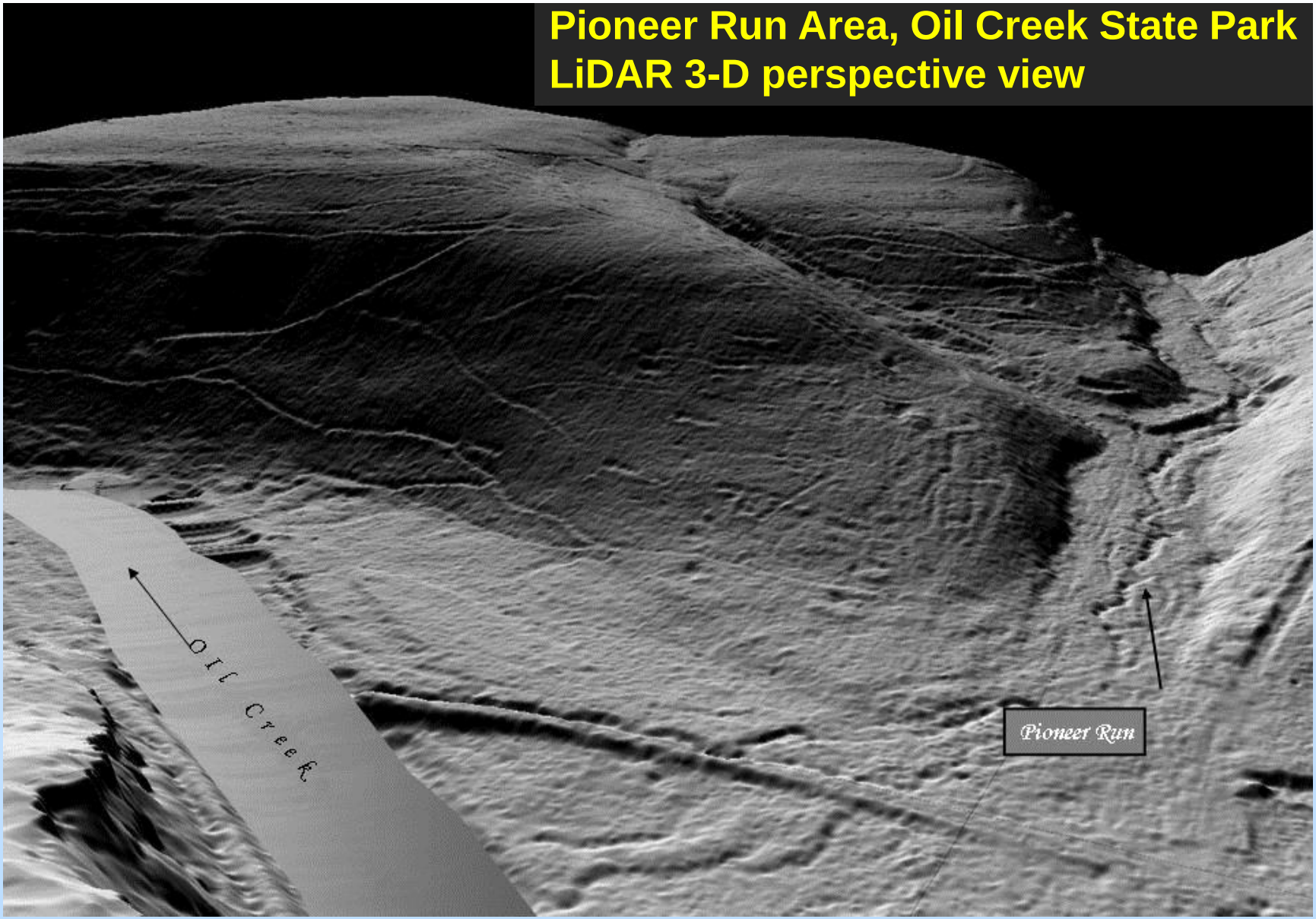
Oil Creek State Park







Oil Creek State Park



Oil Creek State Park

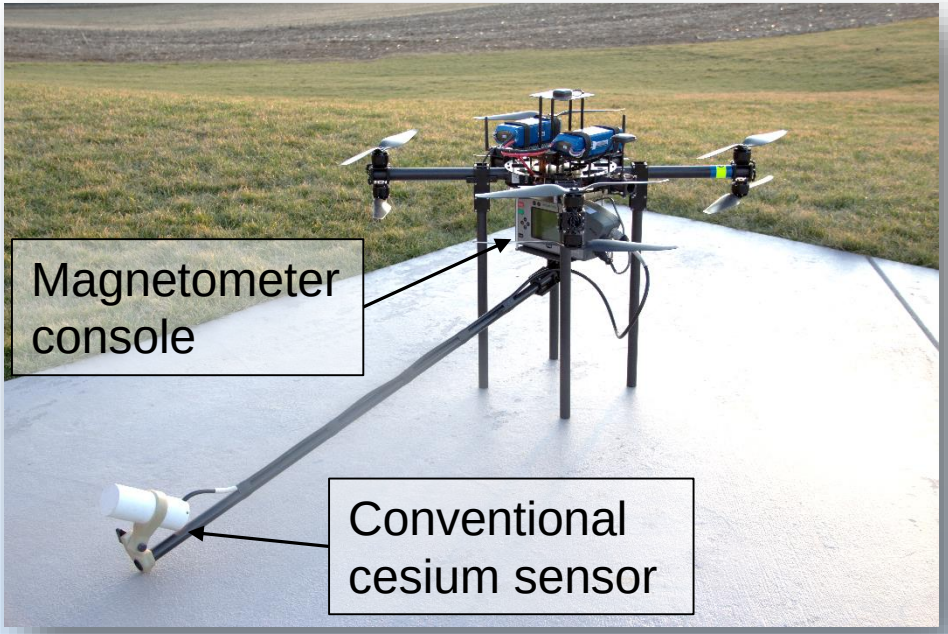
Summary of Results

Flight Area	Spud Dates	Recorded Wells	Found Wells
Marcellus Site	1900-1925	6	17
Hillman State Park	1880-1900	33 *	100+ **
Susquehannock SF	Post-1950	38	39
Oil Creek State Park	1859-1990	323	767+

The 33 recorded well locations in PAIRIS were found to be offset an average of 73 meters when compared to the well location for the nearest site found in the aeromagnetic survey.

****19 wells were found to be leaking methane***

Current and Future Work



Issues:

- ✓ Stability
- ✓ Payload
- ✓ Power consumption
- ✓ Induced magnetic noise
- ✓ Mission Endurance
- ✓ Terrain compliance
- ✓ Costs

Current and Future Work

Micro **F**abricated **A**tomic **M**agnetometer

- Small size:

15 cm^3 sensor and 200 cm^3 electronics

- High performance:

~ 1pT/√Hz noise, 1 KSps (GPS Sync), 400 Hz BW

• Low power operation: 2.5W / sensor nominal

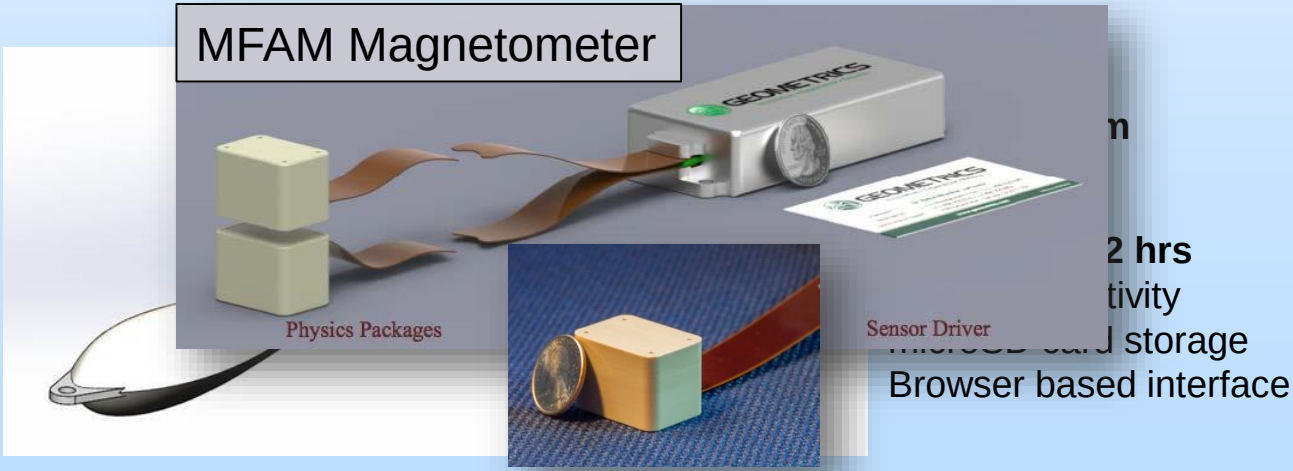
- Light Weight:

Each Sensor: 25 g, Electronics Module: 190 g

• Customizable interface for multi-sensor applications

• Auxiliary inertial measurement sensors

• Dead Zone: Polar, ± 30º



Collaborations

- PA Department of Environmental Protection
- Geometrics Inc.
- RZI Drone Operators
- Spatial Analytics Inc.
- US Aerial Video Inc.

Accomplishments to Date

- Won an R&D 100 award in 2007
- Method successfully located wells in Oil Creek State Park, the oldest wells in the world and the most difficult to locate.
- Performed aeromagnetic surveys over 4 sites for purpose of locating legacy wells and improving existing databases in the context of streamlining permitting process and reducing environmental impacts associated with unconventional O&G development.
- Processed, mapped and cataloged aeromagnetic data for selected well targets using complimentary geophysical methods/modeling and fugitive methane measurements.

Accomplishments to Date

- Performed ground reconnaissance of selected targets and validation by ground magnetic method.
- Amend PA-IRIS wells database for Study Areas
- Established a well characterized test site (Hillman State Park, PA) having unique sets of challenges for well finding that will be used to evaluate miniature geophysical sensors aboard UAS platforms.
- Located and evaluated candidate unplugged well locations for fugitive methane emissions monitoring
- Bench testing of MFAM. Composed software to read and parse MFAM binary data, and perform custom TCP communications with microprocessor/controller for data acquisition and logging.

Synergy Opportunities

- Established partnership with PA Department of Environmental Protection/DCNR for access, data sharing and for purpose of monitoring and characterization of legacy well sites on State lands.
- Established partnerships with RZI Drone Operators, US Aerial Video, Inc., and Spatial Analytix, Inc. for the development and testing of unmanned aerial platforms carrying miniaturized magnetic sensors and photogrammetric imaging/terrain modeling.
- Established collaboration with Geometrics, Inc. and acquired a prototype MicroFabricated Atomic Magnetometer (MFAM) for bench testing and evaluation. MFAM was developed by under a DARPA grant.

Summary

- Findings - Developed rapid and effective methods to locate wells with steel casing; currently working on promising method to locate wells where casing is missing.
- Lessons Learned – Survey design parameters
- Future Plans – Use of UAV platforms to decrease cost

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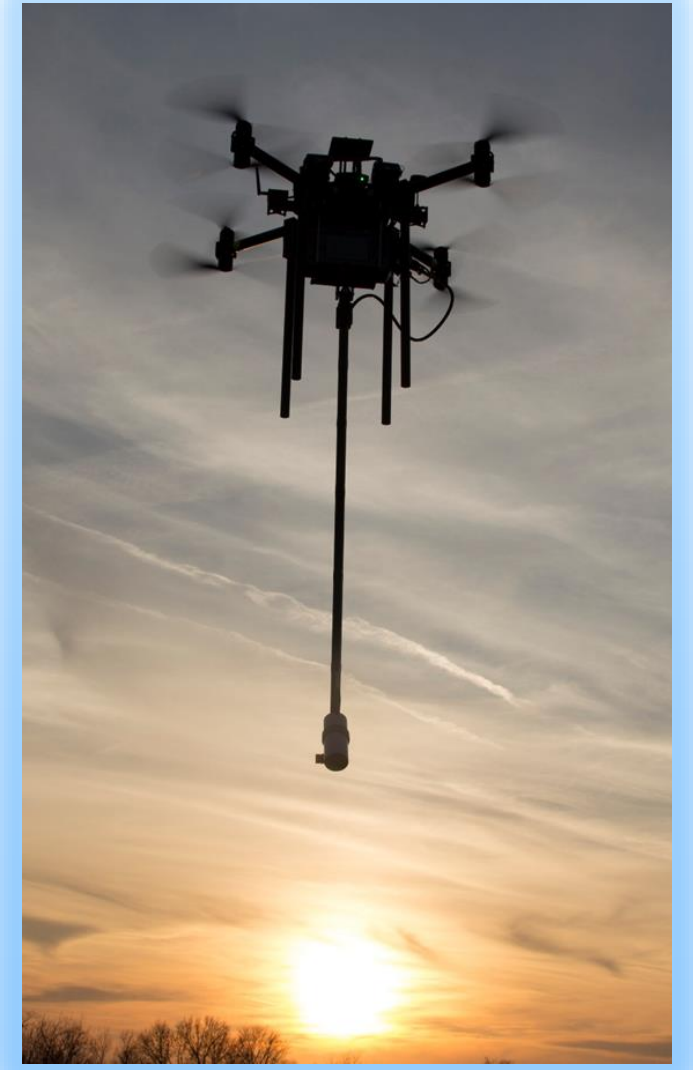

Organization Chart

- Describe project team, organization, and participants.
  - All work performed by NETL's Field Monitoring Team except helicopter surveys, which were performed by an airborne geophysical contractor

Gantt Chart

Phase	Duration	Funding	Outcome
1	2005-2007	Carbon Storage	Two oilfields surveyed in WY; R&D 100 Award
2	2012-2014	EPAct Section 999	4 Large areas surveyed in PA
3	2014-1016	Onshore Unconventional	Ground confirmation of airborne survey.

Bibliography

Sams, J.I.; Veloski, G.A.; Hammack, R.W.; Diehl, R.J., 2016, Methods and Challenges to Locating Legacy Wells in Western PA: Case Study at Hillman State Park: Environmental Geosciences (a peer-reviewed AAPG Journal, Accepted for publication, In Press).

Hammack, R.W., Veloski, G.A., 2016, NETL-TRS-5-2016 Methods for Finding Legacy Wells in Residential and Commercial Areas.

Hammack, R.W., Veloski, G.A., 2016, NETL-TRS-6-2016 Methods for Finding Legacy Wells in Large Areas.

Veloski, G.A.; Hammack, R.W.; Sams, J.I.III., 2016, Results from High Resolution Helicopter Magnetic Surveys Conducted to Locate Legacy Oil and Gas Wells Over two Areas of Future Unconventional Gas Development in western Pennsylvania: Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), 2016, Denver, CO.

Kaminski, V.; Harbert, W.; Hammack, R.W.; Veloski; Sams, J.I.; Hodges, D.G., 2016, Fast and Accurate Helicopter based magnetic geophysical methods for finding wells: Proceeding from the National Academy of Sciences.